	US ATLAS **PHASE II Upgrade** **BASIS of ESTIMATE (BoE)**	**Date of Est:** **21 October 2015** **Prepared by: Robert Walker and John Rutherfoord** **Docdb #:**

WBS number: 6.4.1	**WBS Title: Forward Calorimeter Module 1 and Cold Electronics**

WBS Dictionary Definition:
This WBS covers the design, fabrication, and assembly of the Liquid Argon FCal module 1 and the FCal cold electronics including the cable harnesses for both A and C endcaps. This includes the design and construction of a prototype to finalize electrode gap size and assembly procedures.

The deliverable for WBS 6.4.1 is two (2) sFCal 1 modules, two (2) complete Forward Calorimeter cable harnesses and the 16 cold HV distribution boards (8 for each Forward Calorimeter).

Estimate Type (check all that apply – see BOE Report for estimate type by activity):

___ Work Complete
___ Existing Purchase Order
___ Catalog Listing or Industrial Construction Database
_X_ Documented Vendor Estimate based on Drawings/ Sketches/ Specifications
_X_ Engineering Estimate based on Similar Items or Procedures
_X_ Engineering Estimate based on Analysis
_X_ Expert Opinion

Supporting Documents (including but not limited to): Vendor Quotes

Details of the Base Estimate (explanation of the Work)

This BOE covers the design, prototype, and construction of the Forward Calorimeter module 1 (FCal) A and C ends, the cable harnesses, and cold HV distribution boards for the complete Forward Calorimeter and the cooling loops needed for the additional cooling.

The engineering costs, personnel, and total construction hours are estimated from the original FCal construction schedule completed in 2004.

The materials and machining costs for the FCal are based on quotes received in 2012 and 2013 for the copper plates, rods, ground pins and washers needed to complete the modules, as well as estimates based on previous FCal construction costs for the copper tubes. The prototype cost estimates are scaled down from the FCal costs. The cold electronics, cable harnesses, and cooling loops are estimated from past construction costs as well as experience with and the cost of the materials used. Quotes for materials, where available, are attached in the Assumptions section.

6.4.1 FCAL						
		Labor Hours	Labor $	M&S $	Travel $	Grand Total
6.4.1 FCAL		**31,790**	**1,503,925**	**3,570,000**	**66,000**	**5,139,925**
	Sr. Engineer	1,687	135,762			135,762
	Jr. Engineer	11,544	735,262			735,262
	Technician	5,772	344,433			344,433
	Student	12,787	288,468			288,468
	M&S			3,570,000		3,570,000
	Travel				66,000	66,000

Schedule:

A detailed timeline for the FCal upgrade covering the full scope of the project has been created. This timeline covers design, prototype, and construction for all 3 modules that make up the full FCal. The schedule allocates time for bidding, vendor selection, machining, acceptance testing, parts cleaning, and assembly. It takes into account lead time on parts, machining time, cleaning schedules, and assembly time.

The above labor hours have been extracted from this schedule and only include labor estimated to be needed for the construction phase of the FCal1 module to be done at the University of Arizona. The construction phase includes the finalization of the design, prototype, and construction of the FCal1 modules, cold cable harnesses, and cold electronics.

A course breakdown of the timeline by fiscal year:
Modules:
Early FY19: Design is finalized, prototype is started
Mid FY19: Prototype construction finished, vendor selection completed, part manufacturing started.
Late FY19: Part manufacturing continues, acceptance testing of first received parts, parts cleaning and storage starts
Early FY20: Acceptance testing and part cleaning continues
Late FY20: First FCal1 module assembly starts
FY21: Assembly of first FCal1 module continues and finished
FY22: Assembly of second FCal1 module starts
FY23: Assembly of second FCal1 module continues and finished

Cold Electronics, cable harnesses, cooling loops.
FY19: Designs are finalized
FY20: Cold electronics prototype is completed
FY21: Cold electronics, cable harnesses are manufactured
FY22-23: Cold electronics and cable harnesses assembled and tested, cooling loop is manufactured and tested.

Early in the project, the material costs will be high, due to upfront material and manufacturing costs. As the project continues, the material costs will decrease. Personnel costs will start low, and increase as the project continues. It's expected to peak in the third and fourth year before decreasing as construction on the FCal1 modules is finished.

Assumptions: Present estimates of major material costs are summarized here along with backup documents which indicate the source of these estimates.

Plates: Material: $275,000, Machining: $210,000, Total: $485,000

The construction timeline is heavily influenced by the machining time needed for each copper plate. We estimate that it will take 16-18 months to manufacture all 36 plates needed for the two FCal1 modules. The schedule assumes that machining is done at University of Arizona machine shop which eliminates shipping costs associated with each finished plate. Any problems that arose during the machining process could also be quickly resolved due to close proximity to the assembly location. If plates are manufactured elsewhere, shipping costs will increase the cost.

University Research Instrumentation Center
Cryogenics & Gas Facility
Machining and Welding Center

THE UNIVERSITY OF ARIZONA.
TUCSON ARIZONA

1040 E. 4th Street, Room 235
Tucson, Arizona 85721-0077
Phone: (520) 621-6760
FAX: (520) 621-6333

August 12, 2013

Dear Robert Walker,

This table summarizes the estimate for you project as described below. Please review this information and let us know if you have any questions.

Estimate Job	Forward Calorimeter
Estimate Number	TBD
Estimate Date	August 12, 2013
Estimated Due Date	TBD
Estimate Amount	$275,000
Estimated Machine	$210,000 including 8.1% tax, estimated shipping and installation.
Total Est. Cost	**$485,000 ***

Machining process shown below:

- 36 ea. Copper plates supplied by customer as requested saw cut into diameters.
- 3 ea. aluminum plates used for set up prior to machining copper (forward Calorimeter). This process is to insure and prove machining programs. As well as an inspection fixture for measuring the exact true positions locations per specifications.
- Tooling
- Inspection on Coordinate Measuring Machine (Bridge) X=48.00" Y=94.00" Z=10.00" Spec. 0.0008"
- Delivery of first article 2 months ARO
- One to two machined completed plates to follow (approximately 6 weeks) after first article is accepted by customer.
- This estimate includes the purchase, shipping and installation of a new CNC Hass VF-9/40 Machine.

Thank you for choosing URIC. We hope to work with you in the future.

Sincerely,

Victor Gasho
Director

* Costs here are for budgetary purposes only. Actual costs may vary from those stated above given current labor/material/equipment rates at time of order.

Rods: Rod stock: $189,000, Grinding: $141,750, Ground Pin Hole: $130,500, Total: $461,250

The copper rods used in the FCal electrodes have to be precision ground down to the correct diameter for the electrodes. Current planning assume rod stock has to be supplied to the grinding company; the closest commercially available size to the estimated final rod size is 1/4" round stock typically found in 3' lengths. From that size, two rods could be made. The cost of the rod stock depend greatly on the supplier, several researched sources are shown below; in this cost estimate we used a value falling within that range. Further cost estimation took into account the rough rod stock would need additional machining; quotes attached below are for a potential prototype design, the estimated FCal costs have been scaled up from these quotes to account for the estimated 27000 rods needed to complete both modules. Quotes for the full rod manufacturing procedure would be needed for the complete FCal order to narrow down the estimated cost.

OnlineMetals.com
CUSTOM METAL & PLASTICS SUPPLY

Item	Cut Fee	Price	Quantity	Total
Copper 110 H04 Round 0.25" Cut to: 36"	$20,247.00	$6.72	135	$90,720.00
		Sub-Total:		**$110,967.00**
		Total:		**$110,967.00**

SEQUOIA BRASS & COPPER

	Quantity	Name	SKU	Each	Total
Remove / Update	1350(	Copper 110RRD .25 X 36		$15.99	$215,865.00

Subtotal	$215,865.00
Shipping and Handling	$0.00
Tax	$0.00
Total	**$215,865.00**

Ship to Zip/Postal Code: 85719

Ship to Country: United States

Choose a Shipping option

If we determine another shipping method is more cost effective, our sales dept will call you and advise you of any price changes prior to shipping.

Will Call (SBC Whse) $0.00

Recalculate | Empty Cart

Any changes above should be verified by pressing 'Recalculate' before clicking on 'Checkout'.

McMaster-Carr

Line	Quantity	Product		Ships	Unit price	Total	Delete
1	13500 each	8966K4	Multipurpose 110 Copper, Rod, 1/4" Diameter, 3' Long	2 weeks Need this sooner?	$11.42 each	154170.00	

SANDRAY PRECISION GRINDING,INC
632 GRABLE STREET
ROCKFORD, IL 61109
USA

Ph: 815-226-0660
Fax: 815-226-0769

Quote

Number: 14051 Date: 06-Mar-12

To

UNIVERSITY OF ARIZONA
EXPERIMENTAL ELEMENTARY PARTICLE PHYSICS GRP
TUCSON, AZ 85711

Ph: (520) 626-1493

Quote To

ROBERT WALKER
UNIVERSITY OF ARIZONA
EXPERIMENTAL ELEMENTARY PARTICLE PHYSICS GRP
TUCSON, AZ 85711

Ph: (520) 626-1493

Terms	Ship Via	Salesperson
Net 30	Best Way	

Quantity	Description	Unit Price	Amount
	Line: 001 Expiration Date: 05-May-12 Part: 17.528 LG X .1976 OD Rev: COPPER RODS C'LESS GRIND OD FROM 1/4" STOCK DOWN TO .1976 +.0/-.0003 HOLDING A 32 MICRO AS REQUIRED C11000 COPPER ALLOY MATERIAL NOTE: RODS TO BE STRAIGHT WITHIN .005 AS RECEIVED FOR US TO MAINTAIN SIZE		
3,000	ea	$5.25	$15,750.00
	Additional Charges: SET-UP CHARGE		$35.00
		Total:	$15,785.00

THIS QUOTATION WILL REMAIN VALID FOR 30 DAYS AND MAY BE RENEWED UPON REQUEST

CONDITIONS: The prices and terms on this quotation are not subject to verbal changes or other agreements unless approved in writing by the Seller. All quotations and agreements are contingent upon strikes, fires, availability of materials and all other causes beyond our control. Prices are based on costs and conditions existing on date of quotation and are subject to change by the Seller before final acceptance.

Typographical and stenographic errors are subject to correction . Purchaser agrees to either accept overage or shortage not in excess of ten percent to be charged pro-rata. Purchaser assumes liability for patent and copyright infringement when goods are made to Purchaser's specifications. When quotation specifies material to be furnished by the purchaser, ample allownace must be made for reasonable spoilage and material must be of suitable quality to facilitate effecient production.

Conditions not specifically stated herein shall be governed by established trade customs. Terms inconsistent with those stated herein which may appear on Purchaser 's formal order will not be binding on the Seller. Seller's liability is limited to two times the Seller's price each unless approved in writing by Seller. If parts are not repairable, please advise Seller prior to placing order. If Purchaser finds a nonconformance caused by Seller, failure to give Seller first opportunity to correct the nonconformance will void Seller's liability unless Seller approves in writing.

Univ Research Instrumentation Center

Business Office
1040 E. 4th Street, Rm. 235
Tucson, AZ 85721-0077

Estimate

Date	Estimate #
2/10/2012	Q000468

Name / Address
ACCOUNT TO BE DETERMINED Robert Walker Physics Dept. rwalker@physics.arizona.edu 626-1493

Project
TBD

Description	Qty	Rate	Total	U/M
3000 Copper Rods, deburring of both ends and drilling of 1mm dia. x 6mm deep hole on one end of cu rod. Copper rods supplied by customer. Total Est. Cost includes Mach. Labor, set- up and tooling.	223.07692	65.00	14,500.00	hr
Assuming machinable tungsten, 3000 tungsten rods (supplied by customer), deburring of both ends of the rods and drilling of 1mm dia. x 6mm deep hole on one end tungsten rod. Total Est Cost includes Mach. Labor, set-up and tooling.	335	65.00	21,775.00	hr

Thank you for this opportunity to provide you with this estimate.

Subtotal	$36,275.00
Sales Tax (7.1%)	$0.00
Total	$36,275.00

Tubes: $51,700

This first-pass cost estimate for the FCal electrode tubes is based on the original FCal tube cost and then escalated to FY19. Quotes would be needed for a more accurate estimate.

Ground Pins: $9,250

There is a single pin on each rod, and two ground pins for every group of 4 electrodes on the signal side of each FCal. There are also two pins for every group of 4 electrodes on the opposite face that help hold the electrodes in the module. Each module has approximately 25,000 pins. The quote, attached below, cites a small order; it has been scaled up to account for the roughly 50,000 needed for FCal construction.

Date: Tue, 7 Feb 2012 17:56:25 +0000
From: Nick Dressler <ndressler@aerospacesw.com>
To: "rbwalker@physics.arizona.edu" <rbwalker@physics.arizona.edu>
Cc: Dave Harmeyer <dharmeyer@aerospacesw.com>
Subject: RE: RFQ for Mill-Max Part Number 5601-0-01-15-00-00-03-0

Robert,
Please see pricing and delivery on the Mill-max part you requested. If you would like to place the order please send back to me and I will process. Thank you.
M5601-0-01-15-00-00-03-0, Qty: 5,000pc @ .185ea, Factory stock 7-10 business days
Nick Dressler
Customer Service Representative

Aero-Space Southwest, Inc.
Celebrating 30 Years of Business 1982-2012
21450 N. Third Ave. Phoenix, AZ 85027
Phone: 623-587-5805 Toll Free: 800-289-2779
Fax: 623-516-4355

ndressler@aerospacesw.com / www.aerospacesw.com<http://www.aerospacesw.com>

Your authorized distributor for: Avdel, Emhart, Laird, Pem®, Southco

http://www.aerospacesw.com/Linecard.pdf

Washers: Brass: $1,560, Kapton: $2,005

Every group of 4 electrodes is held in the FCal module by two ground pins on the signal side and a pair of pins on the opposite face. Between each pin and the module face is a brass washer and a Kapton washer. Below are two quotes, one for brass the other for Kapton washers. The quotes show the pricing per washer varies per the quantity ordered. We estimate the project will need approximately 25,000 of each type of washer.

BOKER'S, INC.
STAMPINGS AND WASHERS MADE TO ORDER

QUOTATION
3104 Snelling Avenue * Minneapolis, MN 55406-1937 * USA
Phone: 612-729-9365 * Fax: 612-729-8910
Toll Free: 800-927-4377 * Fax: 800-321-3462
www.bokers.com Email: sales@bokers.com

University Of Arizona
Physics Department
1118 East 4th Street
Tucson, AZ 85721

Quote#: 318459
Date: 2/06/2012

Your RFQ#: WEB 2/06/12

Contact: Ruben Dominguez Phone: (520) 621-4797
Email: rubend1@email.arizona.edu Fax:

Part#: Rev: Bokers Part #: **C116102**
Dimensions: 0.165+/- .005 X 0.051+/- .005 X .010+/- .001 We have a current Blueprint: **No**
Material: BRASS 260 SPRG Internal Use Only: 10R60 xx938N E

Initial Service Charge: $0

Quantity	100	500	1,000	2,500	5,000	10,000
Piece Price	$2.1900	0.5100	0.2690	0.1460	0.0920	0.0550

Notes:
Will tumble if practical.
Quoting a plain flat, round washer to the above specifications.
Pricing does not include certifications or reports.

Delivery: **2-3** Week(s) is our current delivery for this item. Please contact us if this does not meet your requirements.

Quantity Variations: Prices are based on an allowance for a **+or- 0%** variation from the quantity ordered.
If exact quantity is needed please advise.

Split Shipments and Samples: Invoices will be priced at the rate for each quantity shipped where split shipments or samples are requested by the customer.

Quotation: Typographical and clerical errors are subject to correction. Quotations are based on acceptance within 60 days. This quotation is subject to change based on current market price of materials.

Terms: Net 30 days, with approved credit, F.O.B. our plant in US dollars. In acceptance of this quotation, your company agrees to Boker's, Inc. Quotation Terms and Conditions found at http://www.bokers.com/userfiles/file/Bokers-Terms.pdf

Boker's Representative: Tricia Breidel

Thank You

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Phone: 612-729-9365 * Fax: 612-729-8910
Toll Free: 800-927-4377 * Fax: 800-321-3462
www.bokers.com Email: sales@bokers.com

University Of Arizona
Physics Department
1118 East 4th Street
Tucson, AZ 85721

Quote#: 318461
Date: 2/06/2012

Your RFQ#: 2-6-12 Web

Contact: Ruben Dominguez Phone: (520) 621-4797
Email: rubend1@email.arizona.edu Fax:

Part#: Rev: Bokers Part #: **C116103**
Dimensions: 0.250+/- .005 X 0.052+/- .005 X .005+/- .001 We have a current Blueprint: **No**
Material: KAPTON HN Internal Use Only: 10R60 xx938N E

Initial Service Charge: $0

Quantity	100	500	1,000	2,500	5,000	10,000
Piece Price	$2.5800	0.6000	0.3270	0.1790	0.1130	0.0720

Notes:

Edges as stamped.
Quoting a plain flat, round washer to the above specifications.
Pricing does not include certifications or reports.

Delivery: **2-3** Week(s) is our current delivery for this item. Please contact us if this does not meet your requirements.

Quantity Variations: Prices are based on an allowance for a **+or- 0%** variation from the quantity ordered.
If exact quantity is needed please advise.

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Boker's Representative: Tricia Breidel

Thank You

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Cooling loops: $107,100

The cost of the cooling loops was estimated by material cost for the piping, experience with pipes, the cost of manufacturing, and testing. A quote, based on the final design, would be needed to get a more accurate estimate.

HV distribution boards: $410,000

The estimated cost and assembly time needed for the cold electronics was derived from the original FCal cold electronics. This estimate includes: final design work, a prototype, needed components, the PCB size, the time needed for manufacturing, and testing.

Cable harnesses: $750,000

The estimate for the cable harnesses includes the materials, manufacturing, and testing. It was based on the original FCal design.

Cleaning supplies and storage: $280,000

The FCal modules will be assembled in a clean room environment, therefore all materials, tools, and equipment used in the assembly will have to be cleaned extensively. The HV distribution boards and cooling loops will need to undergo cleaning following assembly, and prior to final mounting in the Liquid Argon calorimeter at CERN.

Prices for cleaning supplies was calculated based on online prices and estimated quantities needed, which were derived from the original FCal construction. The final cost will depend on supplier costs as construction progresses.

The original construction of FCal1 stored parts awaiting assembly in sealed bins with a Nitrogen gas flow to eliminate moisture caused oxidization. We are assuming a similar setup. The cost of storage bins and Nitrogen gas will depend on the supplier's price at the time of purchasing.

Tooling: $77,000

Assembling the FCal modules requires custom hand tools and various jigs. At this time, it is unknown exactly what will need to be re-made or purchased and what original tooling can be reused. The estimated cost is a lump sum that would cover the cost of needing all new tooling.

FCal Prototype and Cleanroom: $200,000

Some of the above quotes are for prototype quantities, these quotes were used to estimate prototype cost. The estimate also includes the estimated cost of constructing a clean room. The cleanroom would also be used for the full FCal module assembly.

Additional Assumptions:

The cost to ship completed modules to CERN has been included in the cost, and was estimated using a shipping companies online cost calculator.

Risk Analysis

Schedule Risk:

Probability: moderate, impact: high

Potential Problem:

1. Delays in part manufacturing, plate machining is currently estimated to take 16-18 months to complete at the University of Arizona machine shop. A different manufacturer or machining delay early on could push the start of the first module assembly back several months.
2. Depending on the process needed to manufacture completed rods, additional manufacturing steps could be needed, delaying the delivery of completed rods, potentially delaying electrode insertion.
3. The original FCal module was assembled with electrodes having 250 micron gaps between the rods and tubes. The proposed FCal upgrade has 100 micron gaps. Assembly of a small quantity of electrodes with this smaller gap has been done on a table top model. This has shown that insertion of the rods into the tubes is significantly more difficult and time consuming than with the original 250 micron gap electrodes. The time needed to assemble the electrodes may be under estimated.

Mitigation:

1. Plate machining done at the University of Arizona would allow for immediate assessment of any problems associated with the manufacturing process, reducing the time needed to solve the problems. Shipping delays are eliminated, as the plates are finished they can be moved to the assembly staging area easily. Additionally, having enough funding initially, will allow for machining to begin as soon as the final design is accepted.
2. Additional discussions with rod manufacturers will be needed to understand exactly what process is needed. The earlier the manufacturing can start, the less potential there is for delay when electrode assembly is ready to begin.
3. Further R&D is planned to allow for a better understanding of the assembly challenges. Starting the prototype earlier would allow for a more accurate estimation of the time needed to assemble the new FCal electrodes. It would also allow time for an optimized assembly procedure to be developed. Currently the prototype is scheduled for FY19, enough early funding to start a prototype in FY18 could allow for an additional 6-9 months of extra time to complete the full FCal modules.

Cost Risk:

Probability: moderate, impact: low

Potential Problem:

1. Copper is a commodity and the price fluctuation could potentially affect the final cost of the copper plates, rods and tubes.
2. Many quotes used to determine the cost estimate for the FCal are from 2012 and 2013 and initially for prototype quantities of parts that have been scaled up for FCal quantities needed. Prices on some parts may have a lower per part cost when larger quantities are ordered.
3. Plate manufacturing has been assumed to take place at the University of Arizona, removing any shipping costs associated with finished plates. If the plates are manufactured at an offsite location and need to be shipped to Arizona, substantial shipping fees must be added to the cost (36 plates and shipping crates).
4. Current designs are still changing. Until final designs are set, there will still be a question as to final quantities of materials and parts needed. This will have more of an impact on the HV distribution boards, as discussions continue about whether to have fine granularity (no summing) across all FCal modules.

Mitigation:

1. We do not know the impact the traded price of copper has on the end price of a plate, rod or tube because machining costs add substantially to the price quoted. However, if raw copper prices are significantly higher at the time of construction, it would be safe to assume the cost of the plates, rods and tubes will also increase.
2. As designs near finalization, newer quotes could be acquired to narrow in on the potential cost of the FCal construction.
3. Manufacturing the plates at the University of Arizona would eliminate shipping costs. Also, stated above in Schedule Risks, it would reduce the time needed to address any problems that arose during the machining, as well as eliminate costs that might be accrued by making site visits.
4. As the final design parameters are set for the FCal and the electronics, steps can be taken to narrow in on a final cost estimate. While there are still design changes happening, there will be fluctuations in the estimated cost.

Technical/Scope Risk:

Probability: high, impact: moderate

Potential Problem:

The smaller gap proposed for the FCal modules makes electrode assembly difficult. The impact this will have on the final design and assembly time of the modules can only be determined with the construction of a prototype. Prototype construction will help determine the final gap size. Design changes may have be made and tested prior to any final parts being manufactured leading to delays.

Mitigation:

The earlier a prototype can be funded and started, the sooner we can discover any changes that need to be made in the electrode design or assembly procedures and absorb any potential delays that could result from such changes.

M&S Contingency Rules Applied

50%

The University of Arizona built the original FCal1 modules. T this experience provides a much better understanding of problems that could arise during the construction of the upgraded FCal modules, possibly allowing for a lower M&S contingency.

We now estimate the contingency based on the rules for M&S. It depends on the maturity of the cost estimate.

40-60% contingency on: items with a detailed conceptual level of design; items adapted from existing designs but with extensive modifications, and/or made more than 2 years previous with documented costs. A physicist or engineering estimate uses this level.

Labor Contingency Rules Applied

50%

Original FCal construction at the University of Arizona provides an insight into the labor needed for successful construction of the upgraded FCal1 modules. A lower Labor Contingency could be potentially be applied due to this experience.

We now estimate the contingency based on the rules for Labor. It depends on the maturity of the cost estimate.

40-60% contingency for a task that is not yet completely defined, but is analogous to past activities; for example, a fabrication activity similar to, but not exactly like, items fabricated for other activities; for example, design labor for items similar to, but not exactly like, previous designs.

Comments:

The scope of the construction phase has yet to be finalized. Further clarification is needed on what occurs during the construction phase versus the installation phase.

The outline above is one possible component arrangement the University of Arizona could be responsible for. There are other components to the upgrade that have yet to be discussed, such as construction of the bulkhead, cone, structural tube, and additional cabling from the bulkhead to the cold wall feedthrough. These and even the cooling loops, outlined above, could be assigned to other institutions.

Additionally, the original FCal modules were placed in a test beam. Will the upgraded modules go through a similar testing cycle?